

## Exercise in a Cold Climate

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### SUMMARY

*Dr. Shephard reviews practical advice required by the winter sportsman in relation to more fundamental aspects of the bodily response to cold. Heat loss occurs by radiation, convection, conduction, and evaporation of sweat; this loss must be made good by metabolism if the body is not to be chilled. Convection is the main source of heat loss in the sportsman, and must be minimized by appropriate clothing. Chilling below a body temperature of 95°F is undesirable; temperatures below 90°F are rapidly fatal. Heat is restored to the body by warming, by the "waste" energy of physical activity, and by shivering.*

*Problems of angina and bronchospasm can be minimized by warming and humidifying inspired gas. Aerobic power is affected only slightly by cold exposure. Liability to muscular injuries and frostbite, and the course of acclimatization to cold are briefly discussed.*

**I**NCREASES IN AFFLUENCE and leisure time have led to an increasing proportion of the Canadian population to participate in such winter sports as snowmobiling, downhill and cross-country skiing, snow-shoeing, and ice-sailing. Two simple statistics illustrate this trend — Blue Mountain (Collingwood, Ont.) had 16,000 skiers in 1956, and 160,000 in 1971; snowmobile production increased from about 8,000 in 1964 to 400,000 in 1971.

Such pursuits are fundamentally good for health. Nevertheless, if accidents are to be prevented, the family physician should be prepared to offer his patients advice on cold tolerance and acclimatization, needed levels of fitness, the effects of cold upon performance, and methods of minimizing angina, bronchospasm, frostbite, severe chilling, and injury.

As a homiothermic animal, man is in a delicate state of thermal balance with his environment. Fatal hyperpyrexia supervenes at body temperatures of more than 107°F, and fatal chilling is likely if the body temperature drops below 90°F. In a cold environment, losses of heat occur by radiation, convection, conduction, and evaporation, and these losses must be minimized or made good if body temperature is not to fall. Modern clothing technology and instant housing have overcome many of the problems of our arctic environment, but it is still not unknown for people to die of cold exposure even within large Canadian cities.

### Vascular Reactions to Cold

The extent of radiation, convection and conduction depends upon the transfer of heat from the warm core of the body through the subcutaneous fat to the skin surface. A reduction in skin blood flow thus provides one important regulatory mechanism. Unfortunately, it is effective over only a narrow range of temperatures; cutaneous vasoconstriction normally starts at an environmental temperature of about 88°F, and a minimum skin blood flow is reached at or above normal room temperatures (75-80°F) — assuming, of course, that the blood alcohol is low!

A second vascular adaptation is a constriction of the superficial veins; cold blood returning to the body core is directed to the venae comitantes overlying the limb arteries, and heat is thus exchanged with arterial blood in the proximal part of the limb. However, in extreme cold, these forms of vasoregulation tend to break down, and a paradoxical vasodilatation of the extremities alternates with extreme vasoconstriction. The mechanism may be an intermittent paralysis of the arterio-venous anastomoses, and it can lead to a greatly exaggerated heat loss.

*Radiation* implies the transfer of heat in the form of a wave motion. The extent of radiant losses depends upon

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the gradient of absolute temperatures between the man and surrounding objects. In a shaded and windowless hillside shelter, heat may pass quite rapidly from a man and his clothing to the walls, whereas in open sunlight such losses are offset by radiant energy gained from the sun.

*Convection* is a forced transfer of heat induced by movement of air (or water) at the body surface. The normal barriers to convective loss include the subcutaneous fat, clothing, and a thin film of stationary air in immediate contact with the skin or clothing. The surface film is lost in a wind (hence the incorporation of a 'chill' factor into our temperature scales); it is important to note that the air film is equally displaced by rapid body movements, and for this reason downhill skiing is rather ineffective in maintaining body temperature.

*Conduction* implies a direct contact between the body and a surface at a different temperature, without interposition of air. It occurs through the soles of the feet, and — in less successful skiers — through the seat of the trousers. Normally it is not a major route of heat loss.

*Evaporation* of sweat may occur even in a cold climate if vigorous activity is undertaken while wearing excessive clothing. There is also an inevitable loss of water through the skin (insensible perspiration) and the respiratory tract. With vigorous activity in cold and very dry air, a liter or more of fluid can be exhaled per day; each liter of evaporated water costs the body some 580 KCal of heat due to the latent heat of vaporization.

*Clothing* functions mainly by trapping still air within its fibers, thus restricting convection from the skin surface. The insulation achieved is relatively independent of fiber type, but it can be readily destroyed if the trapped air is displaced by either a high wind or downhill skiing. Thus, as most of us have found by practical experience, the optimum combination is an outer windproof garment with loose air-trapping clothes inside. The outer layer should be waterproof, as insulation is rapidly destroyed by rain or wet snow. The extent of thermal protection should also be readily adjustable, since sweating during a hill climb or a quick visit to the bar can quickly destroy insulation from within. The protective value of clothing is sometimes expressed in arbitrary 'CLO' units; British indoor clothing

has a CLO value of one, and Arctic clothing may provide four or more CLO units.

#### Restoring Heat Loss

It is not desirable that body temperature should drop below 95°F, and clumsiness and discomfort are noted with a 2°F drop in body temperature. How rapidly does this occur? If a man is sitting in a clothing assembly with an insulation of four CLO units, he can easily lose one KCal of heat per minute at a temperature of -40°F. Assuming a body weight of 70 kg and a specific heat factor of 0.83, body temperature will drop 2°F in an hour; this is a not uncommon experience when sitting waiting for the take-off of an aircraft in the Arctic. The heat loss must then be restored by a combination of warming, exercise, shivering and possibly non-shivering thermogenesis.

#### Warming

If body temperature is fully restored by the access of heat to the aircraft cabin, or by standing in front of a blazing lodge fire, the northern adventurer is equipped for a further hour of exposure.

#### Exercise

Most forms of exercise are mechanically inefficient, and 75-90 percent of the total energy expenditure must be dissipated as heat. Recreational pursuits thus add two to 10 KCal per minute to the resting heat production of 1.6-2 KCal/min, and during maximum activity very fit athletes may have a total heat production of 20 KCal/min. Much depends upon the vigor with which a sport is pursued. Downhill skiing and skating each have a net heat yield in the range of two to eight KCal/min. However, owing to the associated increase of air movement, the average skier does not overheat, but merely maintains a comfortable equilibrium.

#### Shivering

As body temperature falls, there is a progressive increase of muscle tone through an alteration in the setting of gamma loop proprioceptive reflexes. Eventually, tone increases to the point where gross oscillation of the body

occurs — shivering is said to have developed. This mechanism can increase body heat production to peaks of four and five KCal./min, although a more usual overall effect is 0.5 KCal./min. Since there is little increase of air movement, it is a relatively effective way of supporting body temperature.

### **Non-shivering Thermogenesis**

Some authors have described very large increases of body heat production in the rat in the absence of frank shivering; they have further related this to a special labile food reserve (brown adipose tissue) used in a cold climate. Whether cold induces a non-shivering thermogenesis in man is more debatable. However, to the extent that shivering is a subjective end-point on a continuum of increasing muscle tone, there is likely to be some increase of resting metabolism before shivering is seen or felt.

### **Cold and Performance**

*Aerobic Power.* How does the cold environment affect human performance? On balance, a small increase of aerobic power might be anticipated. The increase of venous tone improves venous return and thus cardiac stroke volume, while the constriction of skin vessels increases the proportion of the cardiac output perfusing active muscle. On the other hand, the increase of systemic blood pressure increases the work of the heart, while an increase of muscle viscosity and bronchoconstriction increase the work of breathing.

In practice, the effects of environmental temperature upon the maximum oxygen transport during a few minutes of activity are slight; beneficial effects of cold are more likely to be seen in circumstances where venous reservoirs are severely taxed (sustained effort, or exercise performed mainly with the arms).

*Performance.* The increase in tone of the muscles has already been noted. This is coupled with an increase in viscosity, a delayed relaxation of antagonists, some peripheral numbness, and possibly frank shivering. Coarse motor tasks may be performed with increased speed and diminished accuracy, but there is a marked impairment of fine motor skills such as performance of a laboratory bolt-threading task or repair of a defunct snowmobile.

The increase of muscle viscosity and a shift of the force/velocity curve for individual muscles leads to a slowing of performance in all brief speed events. Further, because of slow relaxation of antagonists, the likelihood of muscle tears is increased. The situation is essentially the converse of warm-up, and, if peak performance is desired, local heat and/or prolonged warm-up are necessary.

### **Sustained Effort**

In more sustained effort, the oxygen cost of a given activity tends to be increased by both shivering and non-shivering thermogenesis; however, the difference of energy expenditure between normal and cold environments is more marked in the rat than in man, presumably because

of its large capacity for non-shivering thermogenesis.

*Interaction with Fitness.* Rats living in a cold climate develop a larger maximum oxygen intake than those living in the warm. However, in man, the addition of a cold stress apparently does not increase the aerobic power as developed by physical exercise alone. On the other hand, there is some evidence that people with a high level of physical fitness are more tolerant of sustained exposure to moderate cold, both in terms of sustaining rectal and skin temperatures and also in terms of overcoming cold-induced numbness.

*Acclimatization.* With prolonged exposure to any environmental stress, acclimatization occurs. Cold is no exception to this rule. The extent of adaptation is influenced more by the intensity than by the frequency and duration of exposure. The general level of skin blood flow is commonly reduced with acclimatization in order to conserve heat, but there may be a secondary increase of flow to the extremities, restoring manual dexterity.

Some animals develop an increased basal metabolism, possibly through alterations in thyroid function, but it is less certain that man has the capacity to make such a response. While it has been shown that Eskimos have a high resting rate of metabolism, this may merely reflect the specific dynamic action of their traditional high fat diet.

### **Experimentation**

If careful records are kept during a series of deliberate exposures to cold, over the course of one or two weeks the subjects involved in the experiment shiver less and have fewer complaints; they also perform fine motor tasks more accurately. On the other hand, their body temperatures are sometimes lower than those of unacclimatized men exposed to the same stress, and it thus remains in doubt how far the apparent adaptation is merely habituation to a rather unpleasant situation.

With prolonged residence in the north or repeated visits to cold areas, other tricks are devised to maintain body temperature. Clothing is better chosen, a more forceful pattern of movement is adopted, and windy spots are avoided. Such cumulative experience is hardly physiological acclimatization, but it does much to extend the range of climates that can be tolerated.

In some circumstances, local acclimatization can occur. The immediate response to chilling of the hands, whether by wind or icy water is a brisk rise in blood pressure. However, Eskimos and Labrador fishermen learn to tolerate cold water without loss of manual dexterity, and they also show a greatly reduced hypertensive response to a given period of hand immersion.

International class athletes increasingly face the problem of alternating exposure to extremes of heat and cold. Does a tropical environment destroy cold acclimatization, or vice versa? Dr. E. M. Glaser of London, England and I carried out an experiment a few years ago in which volunteers were exposed alternately to three hours of tropical heat and three hours of arctic cold. The experiment was not

particularly popular with the subjects, but adaptation to each of the environments occurred at least as fast as if they had been presented independently.

Tolerance of body cooling is quite limited. Discomfort and a loss of fine motor skills are seen if the body temperature drops much below 97°F; this is due partly to impaired function of cutaneous receptors, and partly to impairment of muscle proprioceptors. Loss of these control mechanisms inevitably increases the risks of injury. When the body temperature drops to 95°F, there is the added hazard of disturbed judgment, as the functions of the brain begin to fail. Below 90°F (32°C), there is a progressive failure of the normal mechanisms of heat regulation, and death becomes increasingly likely. The change in blood temperature upsets acid/base regulation, and as in surgical hypothermia, there is a substantial risk of cardiac arrest or fibrillation.

#### Pathological Reactions to Cold

*Angina* is frequently induced by exposure to cold. This may be partly because the cold is associated with effort such as walking or snow-shovelling. However, there are two other contributing factors. One is the hypertensive reaction to local or generalized cold. This increases the cardiac workload without producing a compensating increase of coronary blood flow. The second mechanism is a reflex coronary spasm in response to the impingement of icy air upon bronchial nerve endings. Practical suggestions for the patient with angina include the avoidance of a combination of exercise and cold exposure, minimizing skin exposure by the wearing of a face mask in extreme climates, adoption of nose-breathing where possible, and, if vigorous activity makes mouth breathing inevitable, the use of an air warming device of the type recently described by Dr. Terrence Kavanagh, Toronto in the *Canadian Medical Association Journal*.

*Bronchospasm.* Cold air may induce an intense bronchitis and bronchospasm, particularly in patients with chronic chest disease. As with angina, the mechanism is probably a reflex reaction to stimulation of bronchial nerve endings. The obvious remedy is to insist upon nose breathing, thereby using the normal air-conditioning mechanisms of the nasal passages. However, even in a healthy patient, the airflow resistance of the nose becomes excessive at a ventilation of about 40 l./min; this is equivalent to an effort of some seven KCal./min. In patients with nasal obstruction, mouth breathing may occur with quite modest exercise such as brisk walking. In such cases, an air-warming device of the Kavanagh type may be most useful.

*Frostbite* is essentially a form of tissue destruction caused by a local freezing of peripheral tissues. Owing to the substantial osmotic pressure of tissue fluids, freezing does not occur until the part has cooled to about 30°F. Contributory factors are an intense local vasoconstriction, and an excessive air movement over the affected surface; protuberances such as the tip of the nose and the tips of the

ears are thus particularly vulnerable. The feet are also a sensitive area: here, the incoming blood is greatly cooled by venous heat exchange, and, unless the footwear is of good quality, local cooling may occur by direct conduction to the underlying ground surface.

Prevention is essentially by adequate clothing of vulnerable areas. Particular care should be exercised by patients with peripheral vascular disorders, and in some cases vasodilator drugs may be a useful form of prophylactic therapy.

*Injuries* are usually blamed upon poorly tended slopes and excessive enthusiasm on the part of the skier. However, the role of viscous muscles, and impaired cutaneous and proprioceptive sensation, should be emphasized; if a patient is feeling cold, he should avoid any maneuver that is just about safe when he is warmed up.

*Severe chilling.* It is not necessary to travel to the Arctic in order to be severely or even fatally chilled. I have commented already on the occasional deaths in cities such as Toronto; here, lack of activity and general vasodilatation induced by alcohol have been responsible. Dr. Griffiths Pugh of Hampstead, England has described deaths on English hill walks at temperatures as high as 50°F; here, the basis of difficulty has been a lack of activity due to exhaustion and/or injury, coupled with loss of insulation due to wetting of clothing.

A fall into icy water can be fatal in as little as 15 minutes, and even if the water temperature is as high as 40°F, survival is often no more than one hour. Again, loss of insulation is the problem, and survival is greatly extended if the outer garment is waterproof. Swimming may help an obese person to maintain body temperature, but in general it increases the rate of body heat loss and hastens the end. Reflex hyperventilation makes the proper control of breathing difficult, and the problems of the swimmer are compounded by viscous muscles, malfunction of sensory receptors and disturbed judgment.

Treatment of a chilled person is quite difficult, and many die of complications such as respiratory, circulatory and renal failure. The usual plan of attack includes fairly rapid rewarming, assistance to ventilation as required, and injection of hydrocortisone to counteract circulatory failure. Oxygen is given, and the electrocardiogram is monitored for abnormalities of rhythm. Metabolic acidosis and electrolyte imbalance are corrected as necessary.

#### Conclusion

The toll of physiological and medical problems I have discussed may seem an excessive penalty for taking exercise in the cold. Certainly, the severe case of angina or bronchitis is better off in a heated pool or gymnasium. But given adequate clothing and not too excessive periods of exposure, the average patient tolerates the Canadian winter surprisingly well.

In a country where winter lasts almost nine months of the year, it is a great mistake not to learn to live with the snow and cold and to enjoy them.